DNA is the most fascinating four-letter language in history, as it is the basis for our genetic code and that of all of living things. To date, thousands of genes have been identified in organisms ranging from bacteria to trees to fungi to humans. According to the best estimate, we humans have just over 22,000 genes, while *E. coli* bacteria have about 4,400, and a simple virus may have just six or eight. You may have heard that humans and our closest relative, the chimpanzee, share about 99 percent of our genes.

That may not be much of a surprise, considering the similarities in body type. But here's something that may surprise you. About 60 percent of our genes overlap closely with those in fungi: yes, mushrooms, mildew, and mold. How can this be? The simplest answer is that nature is lazy: once it finds a solution to a particular problem, it tends to reuse it. By "solution to a problem," we mean one of the metabolic processes, such as making proteins or oxidizing sugars in order to continue to live, a situation that commonly confronts organisms. Once an early form of life solves a problem, the genes that underlie that solution are passed on to descendant organisms.

We also see this "laziness" in DNA itself. All living organisms, and most viruses, house their genetic code in DNA. Once DNA evolved, there was no need for a better system that would encode the information that an organism needs, so the DNA system was passed down again and again. Indeed, DNA is so important that early organisms evolved a way to "proofread" it after cell division, to correct mistakes. As with other biological solutions, this proofreading mechanism was passed down and is probably active in your cells at this very moment.
The Theory of Evolution through Natural Selection is the Foundation of Biology

**LEARNING OBJECTIVES**

- Appreciate the scientific nature of the theory of evolution.
- Understand the history behind our current "evolution in the classroom" debate.
- Briefly describe natural selection.
- List the five criteria that would allow a population's gene pool to remain unchanging.
- Give two examples of evolution in action.

**Evolution The Theory of Evolution through Natural Selection Is the Foundation of Biology**

Evolution. Even the word can cause an argument. What is evolution? Why does the theory of evolution hold such emotional sway over us, while few scientists give a second thought to the cell theory or the atomic theory? Although the theory of gravity is much less understood than the theory of evolution, we don’t jump out a skyscraper window and claim "gravity is just a theory."

Many who loudly criticize the teaching of evolution have serious misconceptions about what it really means. The theory of evolution, as outlined by Charles Darwin in 1859 and refined by hundreds of scientists in the intervening century and a half, is an explanation for the appearance, relationships, and distribution of the myriad life forms on Earth. Darwin studied life—in the barnyard and the backyard, on islands and volcanoes, in rain forests and deserts—for decades. He attributed the myriad life forms on Earth to natural selection. Natural selection occurs because an organism’s environment may favor one phenotype over another at a given time, so individuals with the "right" phenotype have a greater chance of reaching reproductive-age and passing on their "better" genes to the next generation. The lawyer’s understanding of natural selection is embodied in the phrase "survival of the fittest." Those organisms with the best possible combination of genes for their particular situation, those fit to survive and reproduce, do so, and their offspring do likewise.

The theory of evolution says nothing of a planned universe, an intelligent designer, or any supernatural or external guiding power of any sort. (Natural selection may properly be thought of as an internal response to external and imperative forces acting on the individual, an internal mechanistic guiding power.) Evolution’s two strongest antagonists of thought, creationism and intelligent design, both require the presence of a higher power investing energy in the life forms on Earth.

Although some tenets of the theory of natural selection are difficult to test experimentally, leaving questions that scientists have yet to answer, neither of the alternative suggestions is based on the masses of scientific evidence that uphold the theory of Darwin and Wallace. Both alternatives include nonnatural (supernatural) intervention and therefore cannot be investigated with the scientific method. In fact, they make no testable predictions whatsoever.

Recall that scientific hypotheses must be testable and falsifiable. The overall theory of natural selection is testable despite difficulties in directly testing some of its specifics. Experiments can be designed to show natural selection in action. We see examples all around us; in the rapid change of the HIV virus that can make it resist drugs after repeated exposure, or the appearance of antibiotic-resistant bacteria, or even the changes in prey species that allow them to avoid being eaten by predators.

The principles of creationism and intelligent design are neither testable nor falsifiable. While the statement "God created heavens and Earth" may for argument’s sake be labeled a hypothesis, it is not one that can be tested, and therefore it is not a scientific hypothesis. For this reason, it is incorrect and inappropriate to include such theological or philosophical principles in a science curriculum, except as examples of untestable, and therefore nonscientific, hypotheses.

Nevertheless, as recently as February 2005, members of the Kansas City Board of Education seriously considered adding intelligent design to their high school science teaching curriculum. In April 2005, a public forum to hear constituents’ opinions was held, followed by a formal legal hearing to determine the legality of teaching ID and evolution. The results of these hearings will be difficult to test experimentally, leaving the fact that this issue continues to make the news is significant. There is also evidence that, in order to avoid political controversy, many teachers simply shy away from teaching much about evolution.

**Evolution, school, and politics: a contentious history**

<table>
<thead>
<tr>
<th>State</th>
<th>Year</th>
<th>Ruling</th>
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</thead>
<tbody>
<tr>
<td>Tennessee</td>
<td>1925</td>
<td>The Sequoyah, in which the state bars teaching evolution in classrooms (the Butler law) was challenged. Sequoyah was found guilty of willfully violating the Butler law. The teacher was convicted and sentenced to two years in state prison.</td>
</tr>
<tr>
<td>Kentucky</td>
<td>1972</td>
<td>Public school teachers must teach &quot;the theory of creation as presented in the Bible.&quot;</td>
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<tr>
<td>Alabama</td>
<td>1982</td>
<td>Textbooks must carry a disclaimer stating that evolution is controversial.</td>
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<tr>
<td>Georgia</td>
<td>2002</td>
<td>A federal judge mandated a sticker be put in high school textbooks stating that evolution is &quot;a theory, not a fact,&quot; and that &quot;creationism should be treated with the same level of scrutiny as hypotheses in the natural sciences.&quot;</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>2003</td>
<td>A federal judge ruled that Pennsylvania school districts cannot teach ID in science classes, stating that &quot;teaching Intelligent Design would violate the Constitutional separation of church and state.&quot;</td>
</tr>
<tr>
<td>Alabama</td>
<td>2003</td>
<td>Evolution disclaimer removed from books, but remains in standards urging students to &quot;wrestle with the unanswered questions and unsolved problems still faced by evolutionary theory.&quot;</td>
</tr>
<tr>
<td>Arkansas</td>
<td>2005</td>
<td>ACLU and school officials in Berkeley, Oregon sued over the legality of stickers placed in ID textbooks questioning the theory of evolution, stating that evolution alone is not adequate to explain the origin of life.</td>
</tr>
<tr>
<td>Kansas</td>
<td>2005</td>
<td>Kansas State Board of Education required evolution to be taught as a critical thinking exercise rather than a scientific theory, with ID included in a similar alternative.</td>
</tr>
<tr>
<td>Maryland</td>
<td>2007</td>
<td>State Board of Education approved a biology text that emphasized the importance of the theory of evolution in biology.</td>
</tr>
<tr>
<td>Missouri</td>
<td>2005</td>
<td>State Board of Education required biology text used in high school to include at least one or two chapters that critically examined the theory of evolution.</td>
</tr>
<tr>
<td>Ohio</td>
<td>2005</td>
<td>State Board of Education voted in favor of a curriculum emphasizing the &quot;debates over evolution.&quot;</td>
</tr>
</tbody>
</table>
You may decide, for personal reasons, that creationism makes more sense to you as an explanation for the natural world, but to be a responsible citizen and take an active part in this debate, you must have a clear understanding of the theory of evolution. Evolution is so central to a biological view of the natural world that it is often called the unifying theme of biology. Nothing in biology makes sense except in the light of evolution, said a world-class, high-reputed Russian American biologist almost a century ago, and it’s even more true today, as yet more evidence for evolution accumulates. Let’s take a look at the theory of evolution and specifically at how it relates to the study of human biology.

Evolution equals changes in the gene pool

Charles Darwin’s evidence for his theory of evolution through natural selection is presented in the I Wonder box on page 634. How did Darwin figure out this theory of evolution? Curiously, Darwin seldom used the word “evolution” in his epochal book, On the Origin of Species (1859). Instead, he preferred “descent with modification,” considering it a better description of his ideas. Darwin proposed that natural selection caused the modifications he and other scientists documented. His definition of natural selection included four general statements:

1. All organisms produce more offspring than can survive and reproduce in subsequent generations.
2. Organisms show differences that can be inherited.
3. Variations among organisms can increase or decrease each individual’s ability to reproduce.
4. Variations that increase the likelihood of successful reproduction will be passed on to future generations.

Darwin recognized that the excessive number of offspring in natural populations caused competition for resources like food and shelter, and that individuals with more ability to acquire these resources would survive and reproduce, so traits that helped the parents survive would be passed to the next generation.

After many years, and despite our understanding of the molecular processes of evolution, no one has yet found a basic flaw with Darwin’s notion of descent with modification. The current picture of evolution is as an unpredictable and natural process of descent over time through genetic modifications. The important phrases in this understanding are: descent over time, genetic modification, and unpredictable and natural.

Evolution takes time. Individuals do not evolve; populations evolve. Although Darwin envisioned gradual and subtle changes that would build up over many generations, we now know that changes can also be rapid. But in either case, evolution alters the frequency of alleles in a population. These allelic differences show up as phenotypic differences in individuals and may eventually cause enough divergence to create new species over long periods of time. Evolution, therefore, is a change in allele frequency in a population over time. Small adaptive changes in allele frequency in a population’s gene pool are called microevolution. The term macroevolution is used when a new species is created through these changes in allelic frequencies in a population’s gene pool, leading to more dramatic changes over longer periods, such as the transformation of a fish into a tetrapod.

THE HARDY-WEINBERG EQUATION SPECIFIES HOW ALLELES CHANGE

Many factors can contribute to changes in allele frequency. Independently, the population biologists Godfrey Hardy and Wilhelm Weinberg described a list of characteristics in a population that would prevent changes in the alleles and their frequencies in the gene pool over time. For no evolution to occur, a population must meet these requirements: (1) The population must be extremely large, in fact, effectively infinite, to eliminate the possibility of random genetic drift. (2) The individuals must reproduce sexually and mate randomly within the population, meaning that the only criteria for mate selection is gender. (3) No random mutations can occur, a condition that does not occur in the natural world. (4) There is no selection pressure on the population. (5) There is no gene flow into or out of the population.

These criteria are useful for describing an ideal or a benchmark model population, even though such a population does not exist in the real world. We know the frequencies of alleles do change in natural populations, and therefore evolution is a continuous, ever-present, and ongoing process. However, this list tells us in which criteria are not being met in a natural population and therefore are the cause of the evolutionary changes in that population.

Hardy and Weinberg were not content to generate a list of characteristics for genetic stability; they also saw a need for a mathematical model to predict allele frequencies. The Hardy-Weinberg equilibrium equation is a mathematical representation of the expected genotypic frequencies in a population that is not evolving. This equation allows us to compare frequencies of genotypes from one generation to the next, looking for differences between the ideal H-W model population and the actual natural population.

The frequencies of two alleles of one gene are designated with the variables $p$ (dominant allele) and $q$ (recessive allele). If there are only two alleles to choose from, the total of the frequencies of $p$ and $q$ must add up to 1. Mathematically, $p + q = 1$. For example, if 52 percent of the alleles in a population code for the dominant trait (unattached ear) and 48 percent are homozygous recessive (have sickle cell anemia), the expected genotypic frequencies are $p = 0.52$ and $q = 0.48$. If the population is not evolving, then the expected genotype frequencies will remain constant over time.

The Hardy-Weinberg equation is $p^2 + 2pq + q^2 = 1$, where $p^2$ represents the frequency of the homozygous dominant, 2pq represents the frequency of the heterozygous, and $q^2$ represents the frequency of the homozygous recessive. The frequencies of the genotypes are based on the expected allele frequencies. The Hardy-Weinberg equilibrium equation is a mathematical model to predict allele frequencies. The Hardy-Weinberg equilibrium equation is a mathematical representation of the expected genotypic frequencies in a population that is not evolving. This equation allows us to compare frequencies of genotypes from one generation to the next, looking for differences between the ideal H-W model population and the actual natural population.

The Hardy-Weinberg formula

$P^2 + 2pq + q^2 = 1$

This formula is used to determine the extent of allelic frequency changes that are occurring in a natural population. It is a benchmark model population, with no selection pressure, no gene flow, and no random mutations occurring. It is used when a new species is created, resulting in vastly different organisms, resulting in vastly different species, resulting in vastly different species.
The theory of evolution through natural selection is rightly consid-
ered a crowning achievement of science. But how did an amateur
naturalist name Charles Darwin figure it out? In the early 1800s,
evolution was in the scientific air, in the sense that somebody
needed it to explain the many life forms that biologists were bringing
back from the far corners of the Earth and various individuals had
speculated about the mechanism.

In that era, science was less compartmentalized than today,
and Darwin was able to draw on many sources, the begin his ma-
terwork. On the Origin of Species (1859) with a discussion of plant
and animal breeding, observing that our crop animals and plants
sometimes produce offspring with what we now call new pheno-
types. By analogy, individuals in natural species could vary.

In 1831, Darwin signed on as naturalist on a round-the-world
voyage on the ship Beagle. From geology, Darwin gained clues to
the nature of time and gradual change. In 1832, the Beagle
stopped in Cape Verde, near West Africa, and Darwin noticed a
band of sea shells and corals in rocks 30 feet above the sea. Logi-
cally, the shells must have been deposited below water, so why
were they above water now? Darwin recalled geologist Charles
Lyell, who argued that Earth was continuously changing. Darwin re-
alized he was looking at evidence for Lyell’s idea. Time matters.

Lyell, who argued that Earth was continuously changing. Darwin re-
alyzed he was looking at evidence for Lyell’s idea. Time matters.

In 1833, Darwin gawked at dinosaur fossils in Argentina, and
in the Galapagos Islands, off the coast of Ecuador, Darwin ob-
served a series of related birds, now called Darwin’s finches, that
had adapted to many different ecological niches. As he wrote in
his diary, “A most singular group of finches, related to each other
in the structure of their beaks, short tails, form of body, and
plumage; there are thirteen species . . . all peculiar to this arch-
pelago.” Species occur in some kind of related groups.

By the time Darwin returned home in 1836, all the ingredients
of his theory were in place: variation, time, competition, change,
death, related groups of species. Darwin had intended to become a country pastor, and he was
a religious man. But he wrote in 1837 that intense exposure to na-
ture changed him: “The old argument of design in nature, which
formerly seemed to me so conclusive, fails, now that the law of
natural selection has been discovered. . . . Everything in nature is
the result of fixed laws.”

But Darwin was in no rush to publish: he worked privately on
his theory until 1858, when he received a letter from Alfred Russel
Wallace, a little-known biological collector. On his own, during an
eight-year expedition through the Malay Archipelago (now Mal-
yasia and Indonesia), Wallace had come up with a strikingly
similar theory.

Darwin immediately saw that Wallace’s ideas closely paral-
elled his own unpublished theory. In 1859, both scientists pub-
lished their parallel papers, describing their common theory that
species vary because some are better suited to survival than oth-
er species. But Darwin had conceived it first, and thus it is correct to give
him primary credit for discovering evolution through natural selec-
tion. Wallace agreed, and the two biologists became lifelong
friends after Wallace returned from the Malay Peninsula.

Despite the fact that the Hardy-Weinberg equa-
tion can help us analyze the course of evolution, keep
in mind that evolution is neither linear nor directed.
One of the largest misconceptions about evolution is
that it is progressive or has an end goal, that it is aiming
toward a perfect life form. Evolution is a natural process,
and it has no more purpose than gravity. However, evolu-
tion can, but does not always, maximize the fitness of a
population. Allele frequency changes that persist in a popu-
lation allow the population to exploit the available resources
more effectively than other or-
organisms. Sometimes these changes form a new species,
with the old one dying off, in a
linear alteration. Or similar
modifications may lead to the formation of two or more
divergent species (Figure 19.2).

Allele changes can also lead to neutral modifi-
cations because some mutations or mistakes in copying
DNA during mitosis have little or no effect on pheno-
types. These neutral modifications are neither beneficial
nor detrimental. But as environmental conditions
change, their significance may change as well. The fit-
ness of any trait is affected by chance events, natural se-
lection, man-made alterations in the environment, and
natural changes to the environment.
Evolution Is Backed by Abundant Evidence

**Learning Objectives**

- List and describe the five types of evidence for evolution.
- Give an example of evolutionary change, supported by evidence.
- What evidence do scientists use to support, or refute, the theory of evolution?

New species just don’t appear in our backyards very often, at least in the human time frame. No one person has witnessed macroevolution, although thousands of studies have detected it over long periods of time.

A classic example of how changing selection pressure affects fitness appeared in the peppered moth populations (*Biston betularia*) of Britain. Before industrialization, the peppered moths included a small number of moths with black wings and a higher percentage with light wings. Peppered moths rest with their wings open. The lighter wings camouflage the moths on gray (and lichen-covered) tree bark, but the darker moths made an easy target for birds. As dark soot from factory pollution built up on the trees, selection pressure shifted to favor the darker moths, and the lighter ones were disproportionately eaten. The frequency of the dark allele in the moth population increased as the frequency of the lighter color allele decreased. But as air pollution laws controlled factory pollution, tree bark once again became lighter. The peppered moth population began to decline, with lighter colored moths once again predominating.

A similar phenomenon appeared among moths in Michigan, again tracking the rise and fall of air pollution. In 1895, approximately 98% of the peppered moths around Manchester were dark colored, again at-

Another compelling example of evolution is the current rise of antibiotic-resistant bacteria (see Chapter 10). Antibiotics place enormous selective pressure on bacterial populations. If one bacterium gains a plasmid (an extra circular bit of DNA carrying functional genes) that confers resistance to that antibiotic, the bacterial cell may survive and thrive. Alternatively, a single bacterium may already possess small phenotypic differences that allow it to survive the antibiotic. This single bacterium can reproduce where others cannot, producing a new colony of antibiotic-resistant bacteria.

Since we cannot observe macroevolution directly, how do we determine the scientific validity of the theory of evolution? The main lines of evidence are the fossil record, biogeography, comparative anatomy, comparative embryology, and comparative biochemistry.

**FOSSILS ARE THE OLDEST EVIDENCE FOR EVOLUTION**

Fossils are evidence of past life that includes teeth, bones, seeds, shells, and other hard parts of organisms. A second category of fossils shows evidence of softer tissues. Imprints of leaves, for example, show in the structure of early plants, scientists have even analyzed fossilized dinosaur footprints and feet for hints about dinosaur behavior.

Fossil form when organisms die and are covered with sediment or volcanic ash. The soft tissues usually decompose, but the hard tissues are slowly transformed to minerals. Water percolating through the overlying sediment brings in ions that start a chemical reaction in the organic material, creating a permanent stone body. As more sediment is deposited, heat and pressure build up, speeding fossilization.

The fossil record gives an incomplete but intriguing look at past life. Aside from imprints, soft tissue usually does not fossilize, which means that whole phyla of plants and animals have left no fossil record. We have no fossil record of jellyfish, for example, but we believe they must have been present from a very early time.

Fossils can be dated using simple logic as well as the comparison of layers in diverse areas. For example, it is clear that older layers of sediment are beneath newer layers. It is also logical to assume that fossils found within a particular layer are the same age as that layer. By accepting these two assumptions, fossils can be arranged in order from older to younger. This type of comparison is referred to as relative dating and is used to begin identification of fossil remains.

A second, more accurate way to date layers uses radiometric dating (Figure 19.4), which takes advantage of the fact that radioactive elements decay at well-understood rates. During decay, these elements release radioactive particles and move down an isotopic "decay chain," eventually forming stable atoms. The amount of time it takes for 50 percent of a particular radioactive isotope to convert to another isotope, which may or may not be stable, is called its half-life. During the

**Radiometric dating** Figure 19.4

When an organism dies, the radioactive carbon in its skeleton is fixed. Over the years, as the bone ages, the carbon 14 decays. By the end of one half-life, the amount of radioactivity within the femur is half of that expected from a recently formed bone. After a second half-life, the remaining radioactivity will be only one-fourth of that in new bone. With each passing half-life, the amount of radioactive carbon 14 is cut in half. Knowing the exact half-life and the original concentration of the radioactive isotopes, we can determine the age of the bone.

Fossils can be aged by looking at the strata where they reside. Sedimentary rock is deposited in layers, one on top of the previous one, creating a repeated layered cake effect (Figure 19.3). You can see millions of years of sedimentary rock at the Grand Canyon. Although the strata form horizontally, geological forces can cause uplifting or faulting that tilts or disrupts the sedimentary layers. If you know when a particular stratum was deposited, you can tell the age of the fossils it contains. These layers
Carbon Dating: Was this the Shroud of Turin?

This artifact was originally thought by some to be the shroud used to cover the body of Christ after his crucifixion. Carbon dating of a small section of the material, with its apparent bloodstain, was performed to determine the age of the shroud. This technique indicated that the shroud was not old enough to have been used during Christ’s time period.

PLATE TECTONICS: SHIFTING CONTINENTS SHOW EVOLUTION

Another key to interpreting the fossil record is plate tectonics. The crust of the Earth is not a solid sheet, but rather a patchwork of huge fragments. Each fragment, or plate, may consist of ocean floor, continental land, or a combination of the two. These plates form the Earth’s crust, which floats on the relatively fluid asthenosphere. Convection currents in the asthenosphere rise and transfer heat from the core of the Earth. When they reach the crust, they may flow sideways, pulling and pushing the plates from their original positions.

Convergent zones

These zones form mountains, subduction zones form oceanic trenches, and often nearby strings of volcanoes, divergent zones form oceanic ridges and continental rifts, and transverse zones are extremely unstable. The Pacific Ocean holds the most active plates on the planet. Some more relative to nearby plates at a blistering speed of up to 15 centimeters (about 6 inches) a year. Surrounding the Pacific Ocean, the “Ring of Fire” has more seismic and volcanic activity than anywhere else on the planet. The ring is located at the intersection of tectonic plates encircling the Pacific.

This movement of plates causes the phenomenon called continental drift. Geologists believe that about 200 million years ago, all the continents were connected in one large landmass called Pangaea, which broke into smaller continents (Figure 19.7). These pieces, today’s continents, drifted away from Pangaea to today’s position, carrying both fossil-bearing rock and current
life forms. This movement separated the fossil record. Imagine dividing a completed jigsaw puzzle into seven pieces, to see the whole picture, you would have to fit those pieces back together.

In 1917, German meteorologist Alfred Wegener noticed identical fossils on either side of the Atlantic Ocean. Wegener recognized that most of the early life forms living on the land could not have crossed the Atlantic, so he proposed that the land must have been one large piece. In other words, he hypothesized that Pangaea must have existed. Not until the 1960s was his proposal finally taken seriously, after scientists mapping the ocean floor discovered that the newformed crust at the midoceanic ridges could provide a mechanism for continental drift. In interpreting the fossil record, scientists must take into account where a particular landmass was located when the fossils were deposited. Therefore, the fossil record not only supports the theory of plate tectonics, but it also records the action of evolution.

When Pangaea split and formed early supercontinents, land animals and plants became isolated. As these life forms reproduced, natural selection and random genetic drift occurred. The climate on a particular continent, the placental wolf are thought to have independently evolved their current dog-like appearance. And

Both marsupial moles and placental moles have short, strong forelimbs for digging and sleek tubular bodies.

COMPARATIVE ANATOMY IS A TRADITIONAL BASIS FOR OBSERVING EVOLUTIONARY RELATIONSHIPS

Comparative anatomy is the study of structural similarities and differences in body forms. Comparative anatomy remains a key piece of evidence for the evolutionary relationships of organisms. Evolutionarily speaking, organs can be homologous and perhaps vestigial, or they can be analogous. Homologous structures were found in different living populations and on a common fossil ancestor are homologous structures (Figure 19.8). Homologous structures have a similar structure but perhaps different functions. When different populations or categories of organisms share homologous anatomical features, they presumably also share a common ancestor. A good example appears in the forelimbs of virtually every vertebrate. Even though some vertebrates use their front limbs for flying, others for swimming, wading through trees, running on all fours, or paddling a canoe; all vertebrate forelimbs have the same basic structure. This observation indicates that the common ancestor of vertebrates is more recent than that of, say, crustaceans and vertebrates. The degree of anatomical similarity suggests how close the relationship is between two organisms. Some structures that serve the same function in different animal groups actually arose independently. Analogous structures share a common function but not
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EMBRYOLOGY PROVIDES MORE CLUES TO EVOLUTION

Embryology, the study of development, provides other clues about evolutionary relationships. Some stages of the developing human embryo are strikingly similar to the embryos in other organisms. Scientists used to say, "ontogeny recapitulates phylogeny." (Ontogeny is development from embryo to adult; to recapitulate is to repeat concisely; phylogeny is the study of the development and history of a species.) So this mouthful of jargon implied that the development from embryo to adult precisely repeats the development and history of that species. This seems to be true with a cursory look at vertebrate embryonic development, but we know this statement is an oversimplification. Human embryos do not pass from a single-cell stage, through a fish-like vertebral stage on their way to becoming a human (Figure 19.10). Our embryo does, however, follow the same pathway as other vertebrate embryos. It is uncanny how human embryos resemble reptile or even fish embryos, and therefore it is easy to see how early embryologists could have interpreted superficial appearances as an inference of phylogenetic relationships.

The phylogenetic tree (Figure 19.11) visually represents the genetic and evolutionary relationships among organisms. When comparing two organisms on the phylogenetic tree, long branches indicate less similarity, while shorter branches indicate closer relationships and/or recent speciation (and therefore less time for divergence).

BIOCHEMISTRY: EVOLUTION IS IN THE GENES

Recent technological breakthroughs have provided even more support for the theory of evolution (Figure 19.12). The structures of both proteins and DNA are biochemical evidence for evolutionary relationships. Closely related species have nearly identical DNA sequences; as the relationships become more distant, we see fewer matching sequences. As species develop separately, mutations build up in the DNA. The longer the two species have been separated, the more mutations will have occurred and the more differences there will be in the DNA. For example, humans apparently diverged from chimpanzees about 5 million years ago. During that time, our DNA mutated and accumulated differences. This difference was recently cataloged by Cornell University scientists, who were looking for the genes that...
CHAPTER 19

Natural Selection Has Far-Reaching Effects on Populations

LEARNING OBJECTIVES
Define fitness in evolutionary terms. Explain how the bottleneck effect, the founder effect, and adaptive radiation affect allele frequency.

One of the Hardy-Weinberg criteria for a non-evolving population is the lack of natural selection. Natural selection refers to many forces acting on species, such as the response to climate, the formation of new mutations, and inter- and intra-specific competition for limited resources. The result of natural selection is successful reproduction of only the best-adapted organisms. This selective pressure is the backbone of Darwin’s theory of descent with modification and is ever-present in nature.

The raw materials for natural selection are the random mutations that occur in DNA and the different genetic combinations resulting from sexual reproduction. Mutations occur in nonessential, even unused portions of the DNA over time, as well as in the genes that determine the phenotype of the individual. These altered alleles can persist for generations, with little or no detrimental effect. An accumulation of these random mutations over millions of years may be enough to produce new species, assuming selective pressures change to benefit individuals with the mutations.

Many people summarize natural selection as “survival of the fittest.” Fitness is the ability of an organism to survive and successfully reproduce, to run 1,000 meters. The key is to leave more copies of your genes in the next generation. A woman who dies at age 25 but leaves six surviving children is biologically more “fit” than a woman who runs marathons and lives to be 98 but only has two children.

When the environment changes, for example, with successional changes in the ecosystem, different pressures are put on the resident life forms. These new pressures may require a different foraging strategy, faster reproduction, or perhaps a faster sprinting speed. Mutations may produce phenotypic variations that are beneficial in a changing environment, conferring an advantage to those organisms carrying the mutation. If these organisms reproduce, the mutations may pass to future generations, eventually becoming more common in the population. For example, as wolves prey on deer, the average speed of the deer population increases. The fastest individuals can escape the wolves, while the slower ones get eaten. Those that outrun the wolves breed and pass on the alleles for larger muscles, faster muscle contraction, or more efficient joints, which produces faster offspring. Natural selection causes individuals with the combination of traits most suited to the environment to reproduce and leave a larger proportion of their offspring in the next generation. Assuming this also holds true for humans, the question in human biology becomes, do civilizations rise and fall due to environmental changes? See the Health, Wellness and Disease box, on page 646 for more on this topic.

POPULATIONS LOSE ALLELES

Stable populations can be devastated by natural events, such as tsunami or a fire. These catastrophic events will upset the balance of the ecosystem and promote evolution without regard to fitness. In other words, those individuals in the path of the disaster die, regardless of their genetic makeups. When a large portion of any population is suddenly removed, the frequency of alleles in the remaining population may not be representative of the original population. This is a description of the bottleneck effect.

In the human population, we witness the bottleneck effect after ecological disasters. The tsunami of December 26, 2004, killed more than 175,000 villagers in Southeast Asia without regard to age, gender, or health. Few individuals from the original populations were left to repopulate their villages. If there is little outside influence, the alleles among the remaining individuals will all be that are available for the next generations. If these alleles occur in a different proportion than were found in the original population, a bottleneck has occurred and the population’s gene pool will be different in future generations, compared to what would have happened if the tsunami had not come.

The best modern example of an ongoing genetic bottleneck is the cheetah. These animals used to live in vast tracts of land from the Middle East to India. Due to loss of habitat and increasing pressures of humans hunting the cheetah and its prey, their numbers have plummeted. Currently, there are approximately 17,000 cheetahs left in the wild. These are isolated in small areas of Africa and Iran, with little mixing between populations. Many surviving cheetah carry a harmful allele that decreases fertility. There may not be enough...
Health, Wellness and Disease

CHAPTER 19

Mass Extinctions Can Be Followed by Regrowth

We have talked about human health throughout this book. Now let’s turn our attention to the health of the societies on which we depend for our collective health, education, support, defense, and culture. History is written by the winners, so we often lose track of civilizations that retreated or failed after a period of economic and cultural glory. Historically, the many examples of declined civilizations include the Maya of Central America and the Norse colony, which occupied Greenland from 1000 to 1400.

Jared Diamond, a professor at the University of California at Los Angeles, has looked at the relationship between environmental damage and the crash of civilizations, in his book Collapse. Why have societies in Japan, the New Guinea highlands, and Switzerland flourished for many centuries, while others declined after a period of prosperity? Diamond outlined five factors that influence the long-term sustainability of a society:

- Environmental damage: Overgrazing, overpopulation, overfishing, and clear-cutting forests can all lead to degradation of land and water, reducing the ability of land and sea to support a population. Long-term damage to soils is occurring in many agricultural regions today; when topsoil washes away or turns saline due to overirrigation, agricultural productivity declines. More people have to work on farms, reducing the surplus labor available for skilled trades, administration, culture, and the military.
- Climate change: Long-term shifts in temperature and rainfall can have disastrous impacts on civilizations that may, for example, have grown dependent on steady rainfall. A drought can cause starvation.
- Hostile neighbors: Military attacks by neighbors often spell doom for various societies. However, Diamond sees many of these conquests as ultimately being caused by environmental destruction.
- Friendly trade partners: Trade partners can become allies in time of need. Our current reliance for oil on allies in time of need. Our current reliance for oil on stalwart countries in the Middle East shows, Diamond argues, how the fate of trade partners can affect both sides of the partnership.
- Society’s response to threats: Highland New Guinea and Japan have both developed management plans to conserve forests and end rapid deforestation, helping to ensure their continued cultural survival.

Other factors also play a role in the destruction of civilizations. For example, occupants of the Western Hemisphere lacked the properly challenged immune system to combat many of the diseases carried by colonizing Europeans 500 years ago. The result was a largely inadvertent genocide as smallpox, measles, and other pathogens swept through Native Americans. And of course the availability of advanced weapons plays a role in who survives to write the history books. But in a world that grows ever-more crowded, Diamond’s broad picture of environmental survival or decline helps provide a framework for intelligent action to make sure our society survives as well.

A similar evolutionary process, called the founder effect, occurs when a small group of individuals splinters off to form a new population elsewhere. The main Hawaiian Islands are a great place to witness the founder effect. The islands are home to many species found nowhere else, called endemic species. The ancestors of these species arrived in very small numbers and then expanded to fill all available spaces. The founding populations likely had a different allele frequency than their continental source populations, so those organisms did not carry a full range of genetic possibilities to their new environment. In adapting to their new island habitats, these founding individuals underwent natural selection to evolve into the present island species.

Gene flow can also create new allele frequencies and sometimes even new species. Gene flow mixes genes from different populations when there is a migration of individuals between populations. When individuals leave one population (immigration) and join another (immigration), they are substituting alleles from one gene pool and adding to the next. Gene flow may affect allele frequencies by delivering new genetic combinations or removing deleterious ones. The allele frequency of people in the United States has been dramatically altered by gene flow. As a simple demonstration, the Native American population has a high percentage of type B blood. Had they been the only founder population in the United States, type B blood would be common, but the most common blood type in the United States is type O, closely followed by type A. Gene flow when individuals immigrated from Europe and Africa has changed these allelic frequencies.

When looking at species development over time, we see periods of rapid speciation alternating with major die-offs, called extinction events. Extinction occurs when a species is completely removed from Earth, because all of the individuals died instead of adapting. For example, the Cretaceous period ended with the best-known extinction event, which extinguished the dinosaurs. Scientists believe that some or all of these mass extinctions were caused by a massive impact of an asteroid or comet, but mammoth volcanic eruptions and other factors may also be responsible.

The opposite of a mass extinction is adaptive radiation. Adaptive radiation refers to changes in organisms resulting from new resource combinations,
Amniotic egg during the Carboniferous period (about 320 million years ago), they became able to reproduce without returning to the water. This seemingly small development opened vast new habitats for vertebrates by allowing them to occupy the centers of the continents, away from aquatic breeding grounds. On the phylogenetic tree, periods of adaptive radiation show up as the sudden appearance of many branches. These blooms of life are often followed by die-offs of less adapted forms.

Adaptive radiation continues to create new species in many parts of the world (Figure 19.14). For example, in Hawaii, a full 50 percent of the organisms going extinct today are things we have not yet even identified. Their utility and their beauty will go completely unrecognized. And while evolution may eventually restore biodiversity to its current levels, the restoration will take millions of years. In biodiversity, as in so many things, a gram of prevention is worth a kilo of cure!
et’s press “rewind” to a time about 4.6 billion years ago to a planetary nebula, a whirling disk of hot gas and dust. Over time, these materials cooled and coalesced, forming the sun at the center and a series of planets orbiting it. Young Earth was an inhospitable place, as it was still semimolten rock, with a liquid core of nickel, iron, and other metals (Figure 19.15).

We have now looked at several processes that have caused life to evolve, survive, or go extinct (Figure 19.16). But how did those processes play a role in the formation and development of life on Earth?

Volcanoes cracked the thin skin of the Earth, releasing toxic gases into the atmosphere. The atmosphere was composed mainly of carbon dioxide, water...
As near as we can tell, life arose on this hot, steamy environment 3.8 billion years ago, less than a billion years after the planet formed. This life consisted of single-celled organisms that were rather similar to certain groups of modern bacteria. Where did these organisms come from? Many scientists believe that life formed from organic compounds, which in turn formed from atmospheric gases interacting with the intense heat, ultraviolet light, and lightning of the primitive atmosphere. In the laboratory, scientists have recreated these conditions and formed some of the molecules that must have been present.

We may never know the exact origin of life, as the evidence is dimmed through the mists of time. Even today, scientists argue fiercely over the first evidence for life, which appears in rocks that have been torturedly deformed by heat and pressure for over 3.8 billion years.

Scientists do agree that complex organic compounds must have been present at the dawn of life. Some scientists believe that organic compounds reached Earth on a comet. Amino acids, simple sugars, and small fatty acids formed and dissolved in the seas, creating a warm, nutrient-rich, oxygen-deficient (because of an oxygen-poor atmosphere) soup. The absence of oxygen may actually have helped because this highly reactive element would quickly have oxidized these complex molecules.

**ORGANIC COMPOUNDS BECOME LIFE**

What caused the giant jump from small nutrient molecules to a living cell (Figure 19.17)? One major possibility is that life arose in pools of geothermally heated water at the spreading centers of the mid-oceanic ridges, where the oceans would have protected the young organisms from asteroids and ultraviolet light. The molecules floating in the seas somehow came together to form self-replicating molecules. The only self-replicating molecules we know of are DNA and RNA. Both are highly organized, making a spontaneous appearance highly unlikely. But of the two, the single-stranded RNA is less complex, and therefore is the focus of speculation about the formation of life. One hypothesis is that RNA assembled on a slick mud flat near the sea. With the mud as substrate, RNA formed, replicated, and perhaps directed the formation of DNA.

DNA is a plausible candidate for the nucleic acid of early life. Scientists think it could have originally directed the formation of DNA, as RNA primers are required for most transcription events. Once created, the DNA could have directed the synthesis of additional RNA and proteins, including enzymes. At some point, RNA probably shifted to its many current functions: directing protein formation, regulating gene expression, transferring molecules precisely, and monitoring timing of events within cells. Logically, the formation of DNA must have come after RNA because DNA is double-stranded, more complex, and more stable. Although a few viruses store these genetic instructions on RNA, most life forms use DNA as their self-replicating molecule, likely due to its stability. The base-paired structure of DNA makes mutations less likely or, at least, easier to identify and correct. At any rate, once self-replicating molecules appeared, independent life was probably not far behind.

Once DNA and other macromolecules were available, what else was needed to form a cell? First, a lipid/protein bilayer was needed to encase this new, self-replicating DNA. The process by which this might have happened is hard to envision, but in the lab, micelles can spontaneously assemble under certain conditions. These hollow, water-filled phospholipid spheres could have been produced spontaneously in the primordial oceans. Assuming the forming spheres captured some DNA, a primitive prokaryotic cell would be the result.

**Process diagram of creation of life molecules from early Earth’s atmosphere**

1. A sample of nutrient-laden water representative of the ancient seas is heated to boiling.
2. The heated water evaporates, carrying with it some of the smaller compounds.
3. As the water vapor is collected in the chamber, electrodes deliver a spark similar to a natural bolt of lightning. The collected gases in this chamber simulate the ancient atmosphere, and the electrodes provide the necessary spark of energy to cause spontaneous molecule formation.
4. Chilling the gases from the simulated atmosphere allows condensation and precipitation of any molecules formed during the “lightning storm.”
5. As the atmospheric gases condense and are collected, the fluid is analyzed for the presence of macromolecules. In this closed system, fluid can be passed repeatedly through these chambers, reconstructing the events that may have occurred in the early atmosphere.

Importantly, these first cells had to be anaerobic. They used the nutrients in their environment and harvested energy from the ambient heat and atmospheric compounds. No molecular oxygen was available at that time to participate in their metabolism (Figure 19.18).

As you’ve noticed, we have spoken tentatively about exactly how life began because we have no good record of that epochal event. Each of the events we

**Anaerobic**

Living and metabolizing in the absence of free oxygen in the surrounding environment.

**Prokaryote containing DNA**

Amazingly, a Planet Forms and Life Begins
The one-year geological calendar should help you get a sense of the relative length of the geological time divisions.

### Period Events

#### Pliocene Human forms (genus *Aegytopithecus*), appear December 31 (mid-day)

#### Eocene Primates appear (50 mya) December 27

#### Paleocene Anthroprid primates appear. November 13

#### Cretaceous Jawed fishes appear. November 28

#### Triassic Jaws appear. November 21

#### Devonian Major extinction (most marine species and some invertebrate phyla. December 2

#### Carboniferous Carboniferous living forms are the first groups to respire. November 20

#### Ordovician Major extinction (most marine species and some invertebrate phyla). November 19

#### Cambrian Multicellular animals appear. February 27

#### Precambrian Life was "content" to live as single organisms for several billion years. Before 3.8 billion years ago, only single-celled organisms (such as cyanobacteria (blue-green bacteria) are thought to be the first photosynthetic organisms.

### One-Year Geological Calendar

<table>
<thead>
<tr>
<th>Period</th>
<th>Epoch</th>
<th>MYA</th>
<th>Major Biological and Geological Events</th>
<th>One-Year Geological Calendar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Pliocene</td>
<td>1.8</td>
<td>End of last ice age; Modern humans appear. Neanderthals appear.</td>
<td>December 31 (11:59 PM)</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Pleistocene</td>
<td>1.5</td>
<td>First rocks form. March 4</td>
<td></td>
</tr>
<tr>
<td>Cenozoic</td>
<td>Eocene</td>
<td>53</td>
<td>First living cells appear. March 29</td>
<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td>Cambrian</td>
<td>54</td>
<td>First living cells appear. March 29</td>
<td></td>
</tr>
<tr>
<td>Precambrian</td>
<td>Pannotia</td>
<td>145</td>
<td>Multicellular animals appear. November 19</td>
<td></td>
</tr>
<tr>
<td>Proterozoic</td>
<td>Ediacaran</td>
<td>260</td>
<td>Multicellular animals appear. November 19</td>
<td></td>
</tr>
<tr>
<td>Late Archean</td>
<td>Archean</td>
<td>38</td>
<td>Multicellular animals appear. November 19</td>
<td></td>
</tr>
</tbody>
</table>

### THE APPEARANCE OF OXYGEN CHANGED EVERYTHING

These early years occurred in an atmosphere with little free oxygen. Then photosynthesis began, perhaps after a series of mutations that led to the formation of chlorophyll! The organisms that developed this photosynthesis could suddenly use the carbon dioxide, water, and light energy to create simple sugars. The present-day cyanobacteria (blue-green bacteria) are thought to closely resemble the first photosynthetic organisms.

Recall that oxygen is a by-product of photosynthesis. As photosynthetic organisms increased in numbers, oxygen began to accumulate in the atmosphere and to react with simple compounds there, such as ammonia, hydrogen, methane, and water. These oxidation reactions removed compounds from the atmosphere and put selective pressure on organisms that could not photosynthesize. Oxygen harms anaerobic cells by reacting with the nutrients these cells need, so anaerobic populations declined, creating the opportunity for organisms that respire aerobically. Aerobic metabolism developed after anaerobic metabolism and photosynthesis. As the atmospheric oxygen level rose, resources shifted, new opportunities arose, and life evolved to take advantage of new conditions. Oxygen in the atmosphere changed the whole course of evolution.

### CONCEPT CHECK

1. **How did photosynthesis change the atmosphere and the path of life on Earth?**

   - Photosynthesis is the metabolic process of creating glucose using light energy, pigments such as chlorophyll, water, and carbon dioxide; the process of carbon fixing observed in green plants, algae, and certain bacteria.

2. **How did oxygen change the atmosphere and the course of evolution?**

   - Oxygen harms anaerobic cells by reacting with the nutrients these cells need, so anaerobic populations declined, creating the opportunity for organisms that respire aerobically. Aerobic metabolism developed after anaerobic metabolism and photosynthesis.

### Evolution

*Amazingly, a Planet Forms and Life Begins*
These organisms showed social behaviors and sexual dimorphism similar to the apes. About 3 million years ago, Homo habilis appeared to share the planet with *A. afarensis*. This organism had a larger brain, new types of teeth allowing it to eat a more varied diet, and perhaps the ability to make and use tools. *Homo habilis* literally means "handy man," and many of these fossils are surrounded by stones that could be primitive tools.

### Learning Objectives

- **Understand** the origins of modern humans.
- **Describe** the characteristics of primates.
- **Differentiate** between *Homo habilis*, *Homo erectus*, *Homo neanderthalensis*, and *Homo sapiens*.
- **Appreciate** the variety in modern humans.
- **Discuss** the evolutionary forces currently affecting the human population.

### The Human Ancestors Are Dead Twigs on the Family Tree

Australopithecus was the first member of the family Hominidae. This organism walked upright, and its cranium was slightly larger than that of previous, nonhuman primates. Interestingly, the first hominid was an omnivore and relatively small in stature. A second Australopithecus, *A. afarensis* (*Figure 19.22*), was slightly larger and, based on dentition, ate like a modern vegetarian.
And 1.8 million years ago, another speciation event produced *Homo erectus* and *H. ergaster*. These lighter, more graceful organisms can be classified as humans, for they had subtle differences in cranial capacity, stature, and gait (see *H. erectus* and *H. ergaster*). Originally, these two were classified together as *H. erectus*. *H. ergaster* was distinguished in 1994, when scientists discovered that their skulls were different. *H. ergaster* has a high skull base, thin cranial bones, a slim brow ridge, and a generally lighter skeleton than *H. erectus*. Both had a swift gait, long muscled limbs, narrow hips, and body proportions like those of modern tropical humans. Sexual dimorphism was effectively lost in this group, indicating that both males and females probably participated in the same societal activities. Infant development was extended, allowing a longer family period for passing on learned traits and culture. These primates continued to make hunting tools and eating equipment. Although scientists are not clear on the exact date, it appears that *Homo erectus* and *H. ergaster* migrated out of Africa approximately 1 million years ago, and began to populate other continents. *H. erectus* may have left Africa to avoid environmental changes during an ice age. They remained a part of the biota of Java as recently as 360,000 years ago, making them contemporaries of modern *Homo sapiens*.

We have all heard of Neanderthals. Some scholars believe that these hominids evolved as a separate species from *H. erectus*. Others think *H. erectus* first evolved into a form that was very close to modern humans, which then gave rise to both modern humans and Neanderthals. Neanderthal fossils are anywhere from 200,000 to 300,000 years old. They show characteristics of our morphology, along with those of *H. erectus*. *H. neanderthalensis* probably represents an evolutionary dead end; however, there is still debate as to its exact position in human evolution. Are Neanderthals and modern humans related closely enough to be subspecies of *Homo sapiens*? In 1964, this was the accepted wisdom, based on anatomical similarities. Apparently, the two existed on Earth at the same time, as indicated by fossil sites in Israel where geologic strata indicate that *H. sapiens* lived at that location before *H. neanderthalensis*. *H. sapiens* could not have lived there before *H. neanderthalensis* if the Neanderthals died out before *H. sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern *Homo sapiens* arrived. We know that *H. sapiens* did not die out; therefore the two must have been around simultaneously. The fiction series *Clan of the Cave Bear* by Jean M. Auel is based on the fossil findings of Neanderthal and modern

**HUMANS HOMO SAPIENS MAKES THE SCENE AND STARTS TO CHANGE EVERYTHING**

It is difficult to pinpoint the exact beginning of *Homo sapiens*. Some scientists believe that all modern humans came from one small population in Africa that splintered, migrated, and populated the globe. This splitting must have happened approximately 140,000 to 100,000 years ago. Wherever *H. sapiens* appeared, they replaced all other hominids. We cannot be certain why, as the fossil record gives no indication of violence between species of hominids, nor does it provide evidence of disease. Did *H. sapiens* really fight and kill Neanderthals? Did Neanderthals fall victim to viruses that did not harm *H. sapiens*? Did Neanderthals breed with *H. sapiens*, eventually losing their characteristics as their genes were diluted in the larger *H. sapiens* gene pool? The questions are tantalizing, but we may never know their answers.

**HUMAN POPULATION DIFFERENCES AND ETHNICITY ARE TANGLED CONCEPTS**

The bottom line on the evolution of humans is that we are all one species. Do we look different? A bit (Figure 19.25). Humans have subtle physical differences that are inheritable and that are usually associated with one group of people. For almost all of our history, human populations were isolated by geographic barriers like forests, deserts, oceans, rivers, and mountains. During this isolation, natural selection, gene flow, bottleneck effects, founder effects, and subsequent natural, and, perhaps, sexual, selection favored different genetic traits in the various populations. These differences formed what we used to call racial differences, such as skin color, hair color, hair texture, eye shape, and body stature. But these subtle differences can be overblown and be used as a tool of oppression more often than a tool of understanding. As a concept, the scientific validity of human races is questionable at best. Genetically, we now know that people can have more genetic differences with their nearest neighbors than they do with people living on separate continents. Some of these traits developed as selective advantages to local environments. Dark skin offers better protection against UV light. Facial features, hair texture, and even blood types may have developed in response to environmental pressures. It is important to remember that phenotypic differences are nothing more than products of that slight genetic variation on the overall successful gene plan of the human species. Now that geographical barriers have been lifted, *Homo sapiens* may become even more uniform in appearance. We can jump on a jet and reach another continent in no time flat. This raises the opportunity for gene flow.

The last step in understanding our role in the environment is to study the environment itself. How do we interact with other organisms? What is our role in the biosphere? Our final chapter will place humans in the ecosystem by looking at the science of ecology.

**CONCEPT CHECK**

- What was the first hominid?
- How do *Homo erectus* and *H. habilis* differ?
- Trace the descent of man, from the first hominid to *Homo sapiens*.
- Discuss the causes of variation in the human population.
The Theory of Evolution through Natural Selection Is the Foundation of Biology

Charles Darwin proposed the theory of evolution in 1859 to explain the diversity of life on Earth. Evolution is a change in allele frequencies in a population over time. Creationism and intelligent design are non-scientific explanations for life. Darwin’s theory is based on natural selection and can be quantified with the Hardy-Weinberg equation.

Evolution Is Backed by Abundant Evidence

Evidence for evolution can be found in many ways. Evolutionary evidence appears as changes accumulate over time in the fossil record. Organisms living in similar ranges of climate and ecological conditions develop similar structures and functions for coping with their environment. Comparative anatomy shows homologous and vestigial structures that are evidence of evolutionary relationships. Developmental similarities also indicate common ancestors. Sequencing the DNA or the protein structure of organisms provides yet another indication of ancestral relationships.

Mass Extinctions Can Be Followed by Regrowth

In recent history, there have been five major extinction events. The Permian-Triassic extinction event destroyed approximately 70% of life on the planet. The dinosaurs became extinct at the end of the Cretaceous period. Asteroid showers, volcanism, and other geological forces may have caused these events. We continue to lose species at an alarming rate, forcing us to look for effective conservation methods. Countering extinction is adaptive radiation, where a new niche is opened and a previously unspecialized phenotype imparts an advantage to those organisms that carry it.

Amazingly, a Planet Farms and Life Begins

The solar system originated as a hot swirling cloud of dust and gas. Hundreds of millions of years after Earth came together and cooled, it became hospitable to life. The earliest life forms were anaerobic bacteria. Some became photosynthetic and released compounds, including oxygen, as a by-product of metabolism. Multicellular plants and animals followed as the atmosphere became more conducive to life as we know it. Humans are neocenturies, having evolved less than 5 million years ago.

Critical Thinking Questions

1. Charles Darwin published his theory of descent with modification in 1859. When the Anglican Church was a dominant force in British society, reflect on what scientific research must have been like at that time, and explain why Darwin’s ideas were seen as dangerous. Why do his ideas still cause concern to some individuals and groups today?

2. Intelligent design is based on the belief that the origin and change of species is directed by some super-intelligent force or being. This theory states that the complex forms of life we see on Earth now could not have arisen simply by chance, but rather that they are the result of an intelligent designer directing the path of evolution. Why is intelligent design not considered a scientific theory? What rules of science does it violate or reappropriate?

3. Evidence, observation, and testing are the cornerstones of scientific investigations. List three types of evidence for the theory of evolution. Tell how each supports the theory, and give specific examples if possible.

4. The Hardy-Weinberg equation is directly related to the information expressed in a Punnett square (see Chapter 18). Prepare a typical heterozygous-cross Punnett square. In each square, indicate the predicted genotype, as well as the correct symbol (p or q) from the Hardy-Weinberg equation. For example, if p = 0.5, q = 0.5, the square that represents z^2, the 2q^2 squares, and the q^2 square. If 36 percent of the population is phenotypically recessive (p^2 = 0.36), what percentage of heterozygous individuals are expected? Solve for q and then calculate p = q = 0.5. Use the resulting values in the H-W equilibrium equation: p^2 + 2pq + q^2 = 1.

5. Humans have a great effect on the evolution of other organisms. What activities do we engage in that directly affect evolution? How do humans affect our own evolution?
CHAPTER 19

SELF TEST

1. The idea that life on earth has been controlled and guided by an extraterrestrial force or higher power is referred to as
a. evolution.
b. creationism.
c. intelligent design.
d. descent with modification.

2. Which of the following is NOT a statement concerning natural selection?
   a. Organisms produce more offspring than will survive.
   b. Organisms show variation that can be inherited.
   c. Variations can alter the individual’s ability to reproduce.
   d. Variations that decrease fitness will be passed on to subsequent generations.

3. The alteration of a population over time to produce a subtle change in that population’s phenotype is called
a. microevolution.
b. macroevolution.
c. genetic flow.
d. genetic drift.

4. In the above equation, solving for p.

\[ p^2 + 2pq + q^2 = 1 \]

b. p and q measure population fitness.
c. allele frequencies in populations never change.
d. p and q measure population fitness.

5. In this figure, what evolutionary process is depicted?

- Genetic flow
- Genetic drift
- Adaptive radiation
- Convergent evolution

6. Using this graph, predict how many half-lives have passed for a bone that contains only 1/4 of the original radioactivity.

- 1
- 2
- 3
- 4

7. The fact that marsupials on Australia and placental mammals on the North American continent share common solutions to life’s problems is an example of
a. homologous evolution.
b. analogous structures.
c. vestigial structures.
d. homologous structures.

8. This device was used to simulate

- Radiation exposure
- Genetic drift
- Random genetic variation
- Genetic flow

9. The label A on this image indicates the
a. tibia.
b. malleus.
c. ulna.
d. radius.

10. Which process most likely developed first?
   a. Photosynthesis
   b. Aerobic respiration
   c. Anaerobic respiration
   d. This information is not given on the figure.

11. In this figure, what evolutionary process is depicted?
   a. Genetic flow
   b. Genetic drift
   c. Bottleneck effect
   d. Founder effect

12. The population of Troublesome Creek suffers from a rare congenital disease obtained through
   a. the reactions occurring on the surface of the early earth.
   b. the effects of oxygen on the early atmosphere.
   c. the formation of complex molecules and eventually life on earth.
   d. the formation of the seas.

13. In this image, you can see
   a. 1
   b. 2
   c. 4
   d. 7

14. Which process most likely developed first?
   a. Photosynthesis
   b. Aerobic respiration
   c. Genetic drift
   d. Founder effect

15. True or false: The opposite of extinction is adaptive radiation.

16. The first member of the family Hominidae that is identified from more than a skull fragment is
   a. H. sapiens
   b. H. habilis
   c. A. aethiopicus
   d. A. afarensis

17. Which of the following periods did NOT include a major extinction event?
   a. Quaternary period
   b. Devonian period
   c. Permian period
   d. Cretaceous period

18. As shown on the above figure, the species of man that has the longest survivorship thus far is
   a. H. sapiens
   b. H. habilis
   c. A. aethiopicus
   d. S. tchadensis

19. The newest line of evidence for evolution is
   a. fossil dating
   b. comparative anatomy
   c. biogeography
   d. comparative biochemistry

20. Which of the following is NOT a statement concerning natural selection?
   a. Organisms produce more offspring than will survive.
   b. Organisms show variation that can be inherited.
   c. Variations can alter the individual’s ability to reproduce.
   d. Variations that decrease fitness will be passed on to subsequent generations.

21. The newest line of evidence for evolution is
   a. fossil dating
   b. Comparative anatomy
   c. Biogeography
   d. Comparative biochemistry

22. The premise of this equation is that
   a. evolution is always occurring.
   b. evolution can be quantified by comparing ideal to observed conditions.
   c. there can be no selection pressure on the population.
   d. gene flow must be prevented.